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POLARIZATION PHENOMENA IN DEUTERON-PROTON BACKWARD ELASTIC SCATTERING, $d + p \to p + d$

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1. Introduction

A direct reconstruction of the deuteron wave function (DWF) from the measured quantities in the framework of the Impulse Approximation (IA) is possible in two types of reactions. That are deuteron electrodisintegration[1] $ed \to e + np$, and also A(d,p)X and p(d,p)d reactions.

Existing experience in the analysis of the mechanism of the $\gamma^* + d \to n + p$ process (γ^* is a virtual photon) indicates a lot of problems for deuteron electrodisintegration. The correct mechanism of such a process must contain obligatorily the following ingredients:

- one-nucleon exchanges in the IA;
- meson exchange currents;
- isobar and quark configurations in the ground state of the deuteron;
- strong nucleon interaction in the final state;
- $N\Delta$-rescattering in the $N\Delta \to NN$ process.

So, additional information from experiments with the nuclear probe is of great interest.

The momentum distributions of fragments extracted from the data of the above experiments with electromagnetic and nuclear probes demonstrate, on the one hand, a substantial discrepancy with the predictions using standard DWF in the IA and, on the other hand, a good agreement with one another [4], which gives serious motivations to search for the explanation of the observed effects not only in deviation from the IA but also in nonadequate standard DWF. Even at the IA level the following questions arise:

- the number of independent components of the DWF (two in nonrelativistic theory including S- and D-waves or four in relativistic theory including S-, P- and D-waves [2], or six in the spurion models [3]);
- what is the argument of the DWF and furthermore the number of them (one as in standard models or two as in spurion approaches);
- off-mass effects for nucleon electromagnetic current $\gamma^* N^* N$ with virtual nucleon N^*.

To determine the behavior of different components of the DWF, one needs to study polarization observables of the above reactions. At the present time such data exist or are in progress only for nuclear probe reactions. Apart from cross sections, such observables as the tensor analyzing power T_{20} and the polarization transfer coefficient from the deuteron to the proton κ have been investigated for the reactions $A(\vec{d},p)X$ and $p(\vec{d},p)d$. Analysis of each of these reactions points out [5, 6, 7] no configuration consisting only of S- and D-waves are compatible with the data within the framework of the IA.

The existing set of data is insufficient to separate the deuteron structure from the reaction mechanism. So, measurements of new polarization observables are needed. They can be obtained using a polarized proton target for backward dp elastic scattering (but not for the reaction A(d,p)X). The measurements of these observables are planning now at Dubna.

2. Amplitude of the d+p → p+d (θ = 180^0) process and general analysis of the polarization effects

Backward dp elastic scattering due to P-invariance and total helicity conservation can be described by only four independent complex amplitudes for the following transition $\lambda_d, \lambda_p \rightarrow \lambda'_d, \lambda'_p$,

$$\begin{aligned} F_{0+\rightarrow 0+} &= g_2(s), \\ F_{++\rightarrow ++} &= g_1(s) + g_4(s), \\ F_{-+\rightarrow -+} &= g_1(s) - g_4(s), \\ F_{0+\rightarrow +-} &= -\sqrt{2} g_3(s), \end{aligned} \quad (1)$$

where g_1–g_4 are so named scalar amplitudes. Of course, all polarization effects can be described in terms of the scalar or helicity amplitudes.

In case of unpolarized target the differential cross section $\frac{d\sigma^{(T0)}}{d\Omega}$ depends only on the tensor polarization t_{20} of initial deuterons:

$$\begin{aligned} \frac{d\sigma^{(T0)}}{d\Omega} &= \frac{d\sigma^{(00)}}{d\Omega}(1 + T_{20}t_{20}), \\ \mathcal{N}^{-1}\frac{d\sigma^{(00)}}{d\Omega} &= 2|g_1(s)|^2 + |g_2(s)|^2 + 4|g_3(s)|^2 + 2|g_4(s)|^2, \\ T_{20}\mathcal{N}^{-1}\frac{d\sigma^{(00)}}{d\Omega} &= -\sqrt{2}\{-|g_1(s)|^2 + |g_2(s)|^2 + |g_3(s)|^2 - |g_4(s)|^2\} \end{aligned} \quad (2)$$

where $\frac{d\sigma^{(00)}}{d\Omega}$ is the differential cross section for unpolarized initial particles, and T_{20} is the analyzing power due to tensor polarization of the initial deuteron. The expressions for the normal (κ_t) and longitudinal (κ_l) polarization transfer coefficient from the vector-polarized deuteron to the secondary proton:

$$\begin{aligned} \kappa_t\mathcal{N}^{-1}\frac{d\sigma^{(T0)}}{d\Omega} &= 3 \cdot Re\{g_3(s) \cdot [g_1(s) + g_2(s) + g_4(s)]^*\}, \\ \kappa_l\mathcal{N}^{-1}\frac{d\sigma^{(T0)}}{d\Omega} &= 3 \cdot \{|\, g_3(s)\,|^2 + 2Re\,[g_1(s) \cdot g_4(s)^*]\}. \end{aligned} \quad (3)$$

If the proton target is polarized, the differential cross section depend on mutual spin orientation of initial protons and deuterons

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma^{(T0)}}{d\Omega}\left[1 + \frac{3}{2}A_t(\vec{S}\cdot\vec{P} - (\vec{n}\cdot\vec{S})(\vec{n}\cdot\vec{P})) + \frac{3}{2}A_l(\vec{n}\cdot\vec{S})(\vec{n}\cdot\vec{P})\right]. \quad (4)$$

One can see that the term $A_t(A_l)$ is responsible for the asymmetry effect when spin orientations of both participants of the reaction are normal(longitudinal) to the direction of the initial deuteron 3-momentum.

In terms of scalar amplitudes the expressions for $A_{t,l}$ are following:

$$\begin{aligned} A_t\mathcal{N}^{-1}\frac{d\sigma^{(T0)}}{d\Omega} &= -2 \cdot Re\{g_3(s) \cdot [-g_1(s) - g_2(s) + g_4(s)]^*\}, \\ A_l\mathcal{N}^{-1}\frac{d\sigma^{(T0)}}{d\Omega} &= -2 \cdot \{|\, g_3(s)\,|^2 - 2Re\,[g_1(s) \cdot g_4(s)^*]\}. \end{aligned} \quad (5)$$

In contrast to the differential cross section and T_{20} they contain the interference contributions $Re(g_i \cdot g_k^*)$.

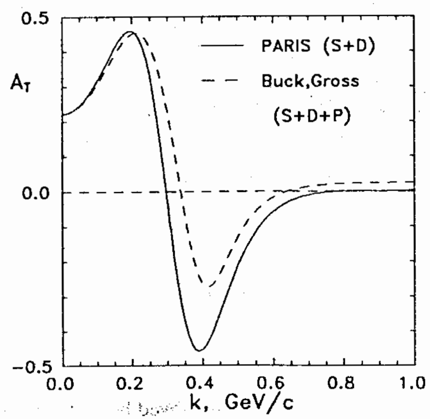
In the IA (one nucleon exchange mechanism) with standard DWF only two amplitudes (real in this case) define all characteristics of the discussed reaction.

The various models of the deuteron with additional P-wave[2, 8] components is compatible with case, when the process is described by four independent (but real) amplitudes. Even a part of mentioned above measurements (for example, cross-sections, T_{20}, κ_t for unpolarized proton target and A_t) are sufficient to determine all amplitudes in this case.

For realization of the complete experiment program it is necessary to obtain data for the polarization observables containing the $Im(g_i \cdot g_k^*)$ contributions. Needed combinations appear only for triple correlations of vector polarizations:

$$\vec{S}_1 \times \vec{S}_2 \cdot \vec{S}_3, \quad \vec{n}\vec{S}_1 \cdot \vec{n}\vec{S}_2 \times \vec{S}_3 \quad (6)$$

and so on, where $\vec{S}_i$ is the polarization vector of an i-particle. We would like to stress that polarization transfer measurements in case all three paricles have various combination of parallel or antiparallel spins, does not provide needed information.



Calculations of A_t performed for one of standard DWF within the IA (fig.), demonstrate rather the scale of the effect than really expected behavior, because, as it was mentioned above, this approach is not compatible with the results of experiments. One can see high sensitivity of A_t to P-wave contribution.

More detailed consideration of all these questions is given in [9].

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